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(54) **METHOD AND APPARATUS FOR DULL FINISH OF ROLL WITH PULSE LASER.**

(57) When a continuous oscillation laser output is to be pulsed by utilizing a Q switch, a conventional method using the Q switch involves a problem that when a frequency is changed, an oscillation excitation condition changes and a pulse waveform and a peak output change simultaneously so that dull finishing cannot be made stably. The present invention reduces an oscillator loss of a laser oscillator at the time of OFF of pulse by lowering a high-frequency signal output to be applied to the Q switch and controls the pulse waveform to a range which is suitable for the dull finish of rolls. An extremely satisfactory dull surface can be obtained in accordance with the dull finishing method of the present invention.

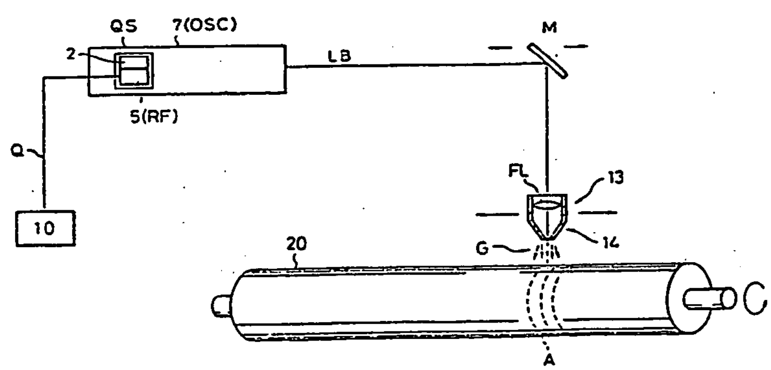

Fig. 10

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DESCRIPTION

TITLE OF THE INVENTION

Method and Apparatus for Roll Dulling by Pulse Laser Beam

TECHNICAL FIELD

The present invention relates to a method and apparatus for dulling a surface of an article such as a roll by a laser beam, and in particular, ensuring appropriate conditions for such dulling by controlling a pulse waveform of a Q-switched laser beam.

BACKGROUND ART

The methods of dulling a roll include, among others, shot-blasting, electric discharge machining, and working the roll surface by a laser.

An apparatus for dulling the roll surface by a laser is disclosed in Japanese Examined Patent Publication (KOKOKU) Nos. 58-25557 and 60-2156.

The apparatuses disclosed in the above Patent Publications dull the surface of a roll with a pulsed laser beam projected from a laser source of a YAG laser, ruby laser, or the like by Q-switching, and are characterized by providing a laser beam splitter which irradiates the surface of a rotating roll (Japanese Examined Patent Publication No. 58-25557) and controls a number of laser beam pulses emitted from the laser beam splitter in accordance with a dulling shape (Japanese Examined Patent Publication No. 60-2156).

To dull the roll surface, the roll surface must be periodically worked with a pulse laser having a predetermined repetition rate, pulse width, and peak value.

Such a pulse laser output can be provided by pulsing a continuous-wave (CW) laser output using a mechanical optical apparatus (chopper, shutter, etc.) as shown in Figure 2, or by using a pulse laser or Q-switched laser beam (as shown in Fig. 3).

In the Q-switched pulse laser, since a mechanical device is not required, the equipment can be made compact and simple and the pulse repetition rate can be easily controlled over a wide range, in comparison with other methods. But, when the frequency is changed by the Q-switching, as shown in Figure 4a and Figure 4b, since the oscillation and excitation conditions vary, the pulse waveform and peak value output are also varied at the same time, and thus a stable dulling cannot be obtained. Also, the peak value ($P\ell_1$) of the leading pulse is very much larger than those of the subsequent pulses ($P\ell_2$, $P\ell_3$, $P\ell_4$, ---), as shown in Figure 1a.

Furthermore, the conventional Q-switched pulse laser beam generally has a fault in that an average pulse peak value ($\overline{P\ell_p} = (P\ell_1 + P\ell_2 + P\ell_3 + P\ell_4)/4$) is 10^5 - 10^3 Watts (W) and a half-power width (tp) is less than 1 micro second conversion of the pulse peak value into power strength (W/cm^2) is shown in Fig. 5), and the working (rater formation) domain is not suitable for dulling. Namely, working parts are evaporated, and therefore, a crater-shaped hole cannot be formed as shown in Fig. 7(a) (height h or depth d of the uneven surface is less than 1 μm).

Japanese Examined Patent Publications No. 58-25557 and No. 60-2156 mentioned above do not disclose a solution to the above problems of the conventional techniques. The dulling of a roll surface of a rolling mill is disclosed in other published documents, e.g., Japanese Examined Patent Publication No. 61-28436 and U.S. Patent No. 4,329,562.

The above JEPP '436 discloses a process in which two luminous fluxes are intermittently focused a lens through a circular rotating plate having a transmission zone and a reflection zone, onto the roll surface, and the above USP '562 discloses a process by which a specific motif or motif patterns are formed on the roll surface of the rolling mill.

The above publications do not disclose a solution to the problems of a Q-switched pulsed laser.

DISCLOSURE OF THE INVENTION

Therefore, the present invention efficiently forms a desired shape crater on the roll surface of the rolling-mill by controlling the nonuniformity, the pulse peak value, and the half-width value of the pulse waveform of a Q-switched pulse laser, which are the problems of the conventional techniques as mentioned above, to the respective domains thereof suitable for dulling a roll, and increases the efficiency of the control of not only a single pulse but also a pulse group.

The invention will be further described with reference to the accompanying diagrammatic drawings.

First, the mechanism of generating the Q-switched pulse laser beam is described as follows, with reference to Figure 3. Namely, a desired excitation energy (light source) is continuously applied to a laser rod 1 arranged between reflecting mirror 3 and 4, and when a Q-switched element 2 composed of a fused quarty, an absorber, and an acousto-optic modulator and disposed between the laser rod 1 and the reflecting mirror 4 at a predetermined angle to a laser optical resonates axis, is supplied with a high frequency signal (this signal is modulated by an RF output modulated signal) from a radio frequency signal source (RF) 5, a diffraction grating is formed inside the fused quarty to generate a diffracted light 6. As a result, the loss inside the resonator 7 is increased and the energy is accumulated in the laser rod 1. Then, when the RF signal applied to the Q-switched element is turned off by an RF output modulated signal, the diffraction grating in the fused quarty is extinguished and the diffraction light 6 eliminated, and the loss in the resonator 7 is decreased. As a result, the energy accumulated in the laser rod 1 is instantaneously radiated to provide a

laser pulse having a high pulse peak value. Namely, as shown in Figure 6, the energy at a level E_{max} is accumulated in the laser rod 1, and when this energy is instantaneously discharged to a level E_{min} ($\simeq$ 0 W), the laser output forms a laser pulse having a high pulse peak value of from P_{min} to P_{max}.

Using the concept that the pulse peak value and half width, etc., of the subsequent pulse can be controlled by controlling the accumulation of energy (E_{max}) of the laser rod 1, the inventors of the present invention effected the following methods:

(1) A method of reducing the pumping energy (light source) which pumped the laser rod 1;

This method is the simplest, but it was found that, where a plurality of pulses is generated in the grouping as shown in Figure 1a, the pumping energy is decreased and the subsequent pulses P_2 to P_4 are eliminated, and thus the number of pulses necessary for working cannot be provided.

(2) A method of inhibiting the accumulation of excessive energy in the laser rod 1 by reducing the loss in the resonator while the pulse is turned off:

This method reduces the value of E_{max} - E_{min} ($\simeq$ 0 W) in Fig. 6, i.e., decreases the E_{max} value, and can be effected in three ways:

(2)-1: Changing the installation angle and position of the Q-switching element 2.

(2)-2: Making the pumping energy sent to the laser rod 1 higher than the upper limit of transmission blocking of the Q-switched element 2.

(2)-3: Lowering the RF power applied to the Q-switched element 2.

It was found from the results of the inventor's experiments that, in any of the above three ways, a constant continuous output P shown in Fig. 1b is generated, the ratio of a leakage output P_L to the total

output P_T can be adjusted by any of these methods, the first pulse P_1 has a reduced pulse peak value ($P_1 < P_{\ell 1}$), the pulse peak value P_1 to P_i of the pulses in the same group can be adjusted to a same level correspondingly, and that the pulse half width t_p is increased ($t_p > t_{\ell p}$).

The method (2)-1 requires an advanced technique for adjustment of the angle and position of the Q-switching element, the method (2)-2 is not advantageous in that the energy consumption is large, and the method (2)-3 is the simplest and most desirable.

Namely, when the RF output applied to the Q-switched element 2 is reduced, the ratio of the leakage output P_L to the total output P_T in the laser rod 1 is increased. Figure 8 shows the above and indicates the correction between the RF output and the leakage output when the total average output P_T is 70 [W] and the maximum RF output is 50 [W]. It is proven that, when the RF output is less than 40 [W] the leakage output increases rapidly. Also, the pulse peak value P_p can be reduced by increasing the leakage output P_L , in accordance with the difference between P_T and P_L , i.e., ΔP ($\Delta P = P_T - P_L$ as shown in Fig. 8), which contributes to the pulse peak value P_p. Figure 9 shows the above and indicates the correction between the leakage output P_L and the average pulse peak value $\overline{P_p}$ and the pulse half width t_p. It is proven that, when the leakage output P_L is increased, the average pulse peak value $\overline{P_p}$ is reduced as shown by curve A and the pulse half width is increased as shown by curve B.

Namely, in accordance with this invention, the leakage output is increased, and therefore, the average pulse peak value is reduced and the first pulse peak value is reduced and thus the first pulse peak value can be maintained at a same level as another pulse peak value in a group. Moreover, the pulse half width can be increased, and therefore, when the roll

surface is dulled by this invention, desired craters can be formed. Figure 7(b) shows the above craters, and thermally-affected zones 12 caused by the leakage output formed on the roll surface. The concavity of the craters can impart a desired roughness to the surface of a rolled steel plates, and since the thermally-affected zones 12 have no irregularities, the rolling of a steel plate can be effected without an adverse affect thereon.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1a and 1b show pulse wave forms for a comparison of the Q-switched pulsed waveform of the conventional technique and of the present invention;

Figure 2 is a perspective view of a method of pulsing the continuous-wave laser beam by a mechanical device such as a chopper;

Figure 3 is a block diagram showing the construction of a solid state laser oscillator using a Q-switched element;

Figures 4a and 4b are graphs indicating the relationship between the frequency and pulse waveform of the Q-switched pulse;

Figure 5 is a graph indicating the relationship between the laser projecting conditions and working phenomenon;

Figure 6 shows a pulse waveform indicating the mechanism which produces the Q-switched pulse waveform;

Figures 7a and 7b show sectional and plan views of a roll surface laser worked by the method according to the conventional technique and the present invention;

Figure 8 is a view indicating the correlation between the RF output and the leakage output;

Figure 9 is a view indicating the correlation between the leakage output and the average pulse peak value and the pulse half-power width;

Figure 10 is a view of the apparatus for dulling the roll surface by a laser of the present invention;

Figure 11 is a block diagram showing the construction of the pulsed laser beam output device according to another embodiment of the present invention;

Figure 12 is a pulse waveform diagram showing the output state of a pulse group according to the present invention;

Figure 13 is a block diagram showing the control circuit for the Q-switching control system;

Figure 14 is a functional time chart showing the relationship among the control signals;

Figure 15 is a block diagram showing the construction of the pulsed laser beam output device according to another embodiment of the present invention;

Figure 16 is a side view showing the state of a focused beam.

Figure 17 is a functional time chart showing the relationship among the control signals;

Figure 18a is a time chart of the generation of a single pulse laser; wherein Figures 18b and 18c are time charts, respectively, of the generation of combined pulse laser;

Figure 19 is a plan view, on an enlarged scale, of the roll surface worked by the pulse laser output device according to the present invention;

Figure 20 are explanatory plan and sectional views of the worked roll surface;

Figures 21a and 21b are block diagrams showing the construction of the dulling system according to the another embodiment of the present invention;

Figure 22a is a view showing the beam combination by the beam splitter, and Figure 22b is a explanation view showing the beam combination by the total reflecting mirror.

BEST MODE OF CARRYING OUT THE INVENTION

An embodiment of the method of the present invention will be described herebelow:

(Embodiment 1)

Figure 10 is a view of the apparatus for dulling the roll surface by a laser of this embodiment.

The pulsed laser beam oscillator (DSC) 7 is a YAG laser oscillator having an average output of over 100 [W], and can oscillate a Q-switched pulsed laser beam LB having a frequency of 1 - 40 kHz. The laser beam LB is made incident onto the roll surface by a plurality of bending mirrors M (only one mirror shown in the drawing) and a focusing lens FL. A laser beam incident head 13 is moved roll-axially by a drive mechanism (not shown). A nozzle 14 is set at a top of the laser beam incident head to emit a gas, e.g., nitrogen, oxygen or argon gas, supplied from a gas supply source (not shown).

The Q-switch QS comprises the Q switching element 2 and the radio frequency signal source (RF) 5.

Reference numeral 10 indicates a controlling system comprised of a circuit which generates the RF output modulated signal Q.

A process by which the surface of a roll 20 is worked by the above mentioned apparatus will be described herebelow.

The pulsed laser beam LB generated by the process, described herebelow, is made incident on the surface of the roll 20, which is rotating at a constant speed.

The signal Q generated from the controlling system 10 is input to the radio frequency signal source RF 5, and the signal is modulated to a desired waveform at the signal source 5 and applied to the Q-switching element 2, where the RF output is controlled (lowered) and the pulse waveform shown in Figure 1b, for example, is generated. The pulsed laser beam LB generated in accordance with the above pulse waveform is made incident on the roll surface.

By controlling the RF input, the most suitable pulsed laser beam for dulling can be irradiated and a crater-shape type motif A can be formed. When the

pulsed laser beam incident head 13 is moved at a constant speed by a drive mechanism, the above mentioned pulsed laser beam is irradiated, and the motif A can be formed on the surface of the roll 20 at regular intervals and as a constant pattern.

Next, the characteristics of Q-switched pulse of the YAG laser in accordance with the present invention and prior art will be compared in Table 1.

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Table 1

		Exciting energy [kw]	RF output [%]	Total average output P_T [W]	Leakage output P_L [W]	Pulsed peak value [W]				Pulsed half-power width t_p ($t_{\ell p}$) [sec]	Energy density [w/cm^2]*
						P_1 ($P\ell_1$)	P_2 ($P\ell_2$)	P_3 ($P\ell_3$)	P_4 ($P\ell_4$)		
Conventional technique		6	100	70	0	$\fallingdotseq 10^5$	$\fallingdotseq 10^4$	$\fallingdotseq 10^4$	$\fallingdotseq 10^4$	$\fallingdotseq 10^{-7}$	$10^7 - 10^8$
Present invention	A	6	40	70	60	$\fallingdotseq 2 \times 10^3$	$\fallingdotseq 2 \times 10^3$	$\fallingdotseq 2 \times 10^3$	$\fallingdotseq 2 \times 10^3$	$\fallingdotseq 10^{-6}$	$\fallingdotseq 10^6$
	B	6	50	70	30	$\fallingdotseq 5 \times 10^4$	$\fallingdotseq 2 \times 10^4$	$\fallingdotseq 10^4$	$\fallingdotseq 10^4$	$\fallingdotseq 5 \times 10^{-7}$	$\fallingdotseq 10^7$

* When beam converging diameter is 100 μm

In the present invention A, when RF output was supplied to the Q-switch at a value 40% less than the conventional technique value, the leakage output became 60 W, the total average output became 70 W, and the output was used to form a pulse of only 10 W, as shown in the above table, and an ideal laser pulse was formed for dulling.

As a result, craters were formed, having a height of the concavity h of 2 to 3 μm, a depth d of 5 to 10 μm, and a diameter D of 100 to 200 μm, as shown in Figure 7b.

Also, in the present invention B, when the RF output was supplied to Q-switch at a value 50% less than the conventional technique value, the leakage output became 30 W and an output of 40 W was used to form the pulse.

Conventionally, in the case A, the output used to form the pulse was 30% higher, the melt evaporation value was increased, the unevenness of the craters was decreased, in that h was 1 to 2 μm, d was 2 to 6 μm, and D was 100 to 200 μm.

(Embodiment 2)

Next, the present invention will be described in detail, whereby a group of laser beams is formed by oscillating a plurality of Q-switched laser beams produced by a Q-switched control system.

Figure 11 shows the basic construction of a pulsed laser beam controller according to the present invention, in which four pulses are used. OSC1 to OSC4 indicate laser oscillators, and OS1 to OS4 indicate Q-switches contained the high frequency signal source RF, and corresponding to the OSC1 to OSC4. Reference number 10 indicates a control system for the Q-switches, from which Q-switched signals Q_1 to Q_4 are output, laser beams LB1 to LB4 are generated by the OSC1 to OSC4 and combined into a group LBP of parallel laser beams by bending mirrors M1 to M7 and combining mirrors

TM1 to TM3. The laser beam group LBP is focused by a focusing lens FL into a focused laser beam group LFP at a focal point FP_0 in such a manner that a single beam is formed. Reference numeral 20 indicates the surface of a roll to be worked. Although four laser beams are shown in Figure 11, the number of laser beams is not limited thereto, since when the number of laser beam is increased, the depth of a hole is almost linearly increased, and thus the number of laser beams is selected according to the quality of the roll surface roughness to be dulled.

Figure 12 shows the ideal pulse waveform for dulling the roll surface. The symbol τ_0 indicates the width of each laser pulse, τ_1 indicates the interval between the first pulse PL_1 and second pulse PL_2 , and τ_2 indicates the interval between the second pulse PL_2 and third pulse PL_3. As shown in Figure 12, the ideal pulse waveform suitable for roll dulling is such that

$$PL_1 = PL_2 = --- = PL_n \text{ and } \tau_1 = \tau_2 = --- = \tau_{n-1}.$$

A circuit diagram of the Q-switch control system 10 is shown in Figure 13, and a functional time chart of the control signals is shown in Figure 14.

As shown in Figure 13, the circuit of the Q-switch control system consists of a pulse generator PG for determining a frequency f_0 of the pulse group, and one-shot multivibrators OM_1 to OM_4 for determining the pulse intervals τ_1 to τ_3 in the pulse group. As shown in Figure 14, OM_1 to OM_4 are synchronous with leading edges of the respective input signals thereof.

Namely, the output signal f_0 from the pulse generator PG is supplied to the clock CK_1 of OM_1 , whereby a pulse Q_1 of the pulse interval τ_1 set at the OM_1 synchronously with the leading edge of the output signal f_0 is generated, and simultaneously, a signal Q, having an opposite polarity to that of the pulse Q_1 is delivered and supplied to the clock CK_2 of OM_2; the pulses Q_2

and $\overline{Q_2}$ are produced in the same way. This also holds true for OM_3 and OM_4.

As described above, the frequency f_0 of the pulse group for dulling is set by PG, and a group of pulses with a predetermined time delay therebetween is generated synchronously with the first signal, and the above pulses Q_1 to Q_4 control a generated signal of the high frequency signal source RF in the Q-switches QS_1 to QS_2 , to thereby effect a control of the Q-switches for the laser beams LB_1 to LB_4.

A roll was dulled by controlling the pulse waveforms of four Q-switched laser beams by the method of the present invention. The waveform controlling conditions of the Q-switched laser pulse beam were as follows:

τ_1 to τ_3:	5 μs
LB_1 - LB_4:	2 kW
f_0:	20 kHz
FL:	25 mm
RF output:	40%

The results of the dulling were a bore diameter of 100 μm and a roughness of 5 μm. The transfer to the steel plate was as high as 80% and the abrasion resistance was also improved.

In the above embodiment, since a peak value can be set for each pulse of a pulse group, the fusing and evaporation during of process dulling an object to be worked in the drilling process for roughening the surface of the object can be more effectively controlled than in the embodiment 1, and craters having suitable shape and hardness can be formed. (For example, a height of a concavity of a crater of embodiment 1 is 3 μm at maximum, but in this embodiment a height of a concavity of a crater of more than 5 μm can be constantly formed.)

Also, since the pulse interval in the pulse group can be controlled, a drilling suitable for dulling can

be conducted. Namely, the present convention is very effective for use in roll dulling.

(Embodiment 3)

In this example, a beam pulse expander BX is set between the laser oscillator OSC and the bending mirror, and therefore, in addition to the effect of the embodiment 2, the diameters of the laser beams (the product beam diameter D and the divergence angle θ is constant) are enlarged, respectively.

Figure 15 shows the basic construction of the pulse laser controller using four pulses according to the above-mentioned embodiment, wherein OSC_1 to OSC_4 indicate laser oscillators, respectively, and QS_1 to QS_4 indicate Q-switches, respectively, and correspond to the OSC_1 to OSC_4 , respectively. Reference numeral 10 indicates a Q-switch control system which delivers Q-switching signals Q_1 to Q_4 , and laser beams LB_1 to LB_4 are generated from the OSC_1 to OSC_4. The laser beams LB_1 to LB_4 have diameters enlarged, respectively, by the beam pulse expanders BX_1 to BX_4 so that the laser beams LB_1 to LB_4 have divergence angles of θ_1 to θ_4. These laser beams LB_1 to LB_4 are merged into a single laser beam group LBP by bending mirrors BM_1 to BM_6 and merging mirrors MM_1 to MM_3.

The laser beam group LBP is focused at a focusing point FP_0 by a focusing lens FL into a focused laser beam group LFP, as in the focusing of a single laser beam. Reference numeral 20 indicates the surface of a roll to be dulled.

The focused diameters d_1 to d_4 of lasers beam LB_1 to LB_4 of the focused laser beam group LFP are the products of beam divergence angles θ_1 to θ_4 and the focal length $f\ell$ of the focusing lens FL, respectively, as follows:

$$d_1 = f\ell \times \theta_1 \ , \ d_2 = f\ell \times \theta_2 \ ,$$
$$d_3 = f\ell \times \theta_3 \ , \ d_4 = f\ell \times \theta_4$$

These focused beam diameters d_1 to d_4 and set peak values can be used to determine the hole diameter and depth worked by the respective laser beams.

As shown in Figure 15, by controlling the beam angles ϕ_1 to ϕ_6 at the bending mirrors BM_1 to BM_6 according to the angle defined by the reflecting plane defined by the pair of merging mirrors, the laser beams in the merged beam group LBP can be made parallel to each other with the angle α defined between the beams in the beam group LBP being zero degree, or not parallel to each other with the angle α being limited.

Namely, as shown in Fig. 15, the laser beams LB_1 and LB_2 , and LB_3 and LB_4 are made incident on the bending mirrors BM_5 and BM_6 as the parallel beams LB_{12} and LB_{34} , respectively, and then as shown in Figure 16, the angle α formed between the merged beams is made $\alpha \neq 0°$ by controlling the beams angles ϕ_5 and ϕ_6 at the above bending mirrors BM_5 and BM_6.

Therefore, the focusing points of the parallel beams $LB_{1,2}$ and $LB_{3,4}$ are displaced to FP_1 and FP_2 , respectively, from point FP_0 (this point is suitable as the focal position at which the laser beam LB is made incident straight into the lens FL in embodiment 1.) where all the laser beams are parallel to one another. In the drawing, X and -X indicate a roll rotating direction and Y and -Y indicate a roll axial direction.

Figure 15 shows the embodiment in which four laser beams are used, but the number of laser beams is not limited thereto and may be more or less. If the number of laser beams is increased, the depth of the hole worked is nearly linearly increased, and holes having a different diameter from one another can be formed according to the number of laser beams. Therefore, the number of laser beams is selected according to the required surface roughness of a roll to be dulled.

Figure 17 shows a functional time chart of the control signals of Figure 16. In Figures 16 and 17, one

dulling is effected by the laser beams LB_1 and LB_2, and the other dulling is effected by the laser beams LB_3 and LB_4. Namely, to make the pulsed laser incident on the surface of the rotating roll, the Q-switching control signal Q_1 is made closer to Q_2 and Q_3 is made closer to Q_4, and thus the Q-switch control time delays τ_1 and τ_3 are shortened and therefore, a dulling effect is doubled. Also, a space between the pulsed laser beams $LB_{1,2}$ and $LB_{3,4}$ can be set at τ_2, and thus a space of a crater at a dulling is determined. This embodiment can operate at double the dulling speed of the above embodiment 2 by using τ_2 in about half of the dulling period thereof.

Figures 18a, 18b, and 18c show the generation of the pulse beam group, wherein Figure 18a shows a pulse train from one Q-switched laser and Figures 18b and 18c show the pulse trains of this embodiment, respectively, which are generated by the control signal shown in Figure 17. Figure 18c shows the pulse train when OM_1 and OM_3 are set at a shorter time than the width W_p of the pulse laser.

The pulse beams of four Q-switched lasers are controlled by the method according to this embodiment to dull the surface under the following conditions:

LB_1 - LB_4:	2 kW
f_0:	20 kHz
T_m:	50 μs
τ_1, τ_3, τ_4:	2 μs
τ_2:	23 μs
FL:	25 mm
FP_1, FP_2:	50 μm
θ_1, θ_2:	3 mrad
θ_3, θ_4:	2 mrad
Roll diameter:	500 mm
Roll speed:	300 to 500 rpm
RF output:	40%

In the above dulling, large and small holes 120 and

80 μm in inside diameter were formed in the pattern shown in Figure 19, and had the sectional shapes as shown in Figure 20. The dulling was made with a roughness of 3.5 μm and the transfer to the steel sheet was 80%, which provided an improved abrasion resistance of the roll.

In Figure 19, when dulling the surface of a roll, W_x shows the space between the n number of trains : N_n and the n+1 number of trains : N_{n+1} when one of the trains of uneven dulling is formed by rotating a roll.

(Embodiment 4)

In this embodiment, a beam splitter BS is used instead of the merged mirror TM of embodiment 2, and coaxially merges the pulse laser beam group.

The "beam splitter" referred to herein is an optical element used to separate a light beam of a predetermined wavelength, when incident at an inherent angle, into a reflected light beam (T) and a transmitting light beam (R). Normally, such an optical element has a structure in which several kinds of substances having different refraction factors are laminated on a base layer of a silica or the like, and due to the characteristics of the laminated structure, the reflected light beam (T) and the transmitting light beam (R) can be polarized simultaneously, as required. In this case, the transmitting light beam (R) of LB_1 is a polarized component (P_{wave}) parallel to the incident plane of LB_1 , and the reflected light beam (T) of LB_2 is a horizontal polarized component (S_{wave}).

Figure 21a shows the basic construction of the pulse laser controller using two pulses according to this embodiment, wherein OSC_1 and OSC_2 indicate laser oscillators, respectively, and QS_1 and QS_2 indicate Q-switches, respectively, corresponding to the laser oscillators OSC_1 and OSC_2 , respectively. Reference numeral 10 indicates a Q-switching control system which delivers Q-switched signals Q_1 and Q_2 sequentially, and

laser beams LB_1 and LB_2 are generated from the laser oscillators OSC_1 and OSC_2 correspondingly. The laser beam LB_1 is supplied directly and LB_2 is supplied through a bending mirror BM_1 to the beam splitter BS, so that a transmitted beam LB_1 (T) of the laser beam LB_1 and the reflected beam LB_2 (R) of the LB_2 are merged into a group LBP_1 of coaxial laser beams.

On the other hand, the transmitted beam LB (T) of LB_2 and reflected beam LB_1 (R) are merged in another direction of the beam splitter BS into a group of coaxial laser beams LBP_2.

The laser beam groups LBP_1 and LBP_2 are focused by focusing lenses FL_1 and FL_2 , respectively, and at the focusing points FP_1 and FP_2 , are focused as laser beam groups LBP_1 and LBP_2 into a single laser beam, thereby permitting a rapid two-divisional dulling of the roll surface.

As shown in Figure 21(b), only the laser beam group LBP_2 merged by the beam splitter is used, and the other laser beam group LBP_2 is not used but is absorbed by a beam damper BD. In this case, the dulling speed is a half of the arrangement shown in Figure 21(a).

Reference numeral 20 indicates the surface of a roll to be dulled. With the two laser beams, the depth of the hole is nearly double and a number of laser beams is selected according to the required quality of the surface roughness of a roll to be dulled.

When the dividing function of the beam splitter by polarization is used and the laser beams LB_1 and LB_2 have 50% P and S waves, respectively, as random-polarized, the relationship $PL_1 = PL_2$ can be obtained by equalizing the powers of the laser beams LB_1 and LB_2 and using the inherent incident angle of the beam splitter (as an incident angle providing a complete separation between P and S component waves).

When the laser beams LB_1 and LB_2 are not completely random-polarized and the P and S waves cannot be sepa-

rated at 50%, the relationship $PL_1 = PL_2$ can be obtained by adjusting the powers of the laser beams LB_1 and LB_2 to the separation ratio between the P and S waves.

In this embodiment, as described in embodiment 2, the frequency f_0 of the pulse group for dulling the roll surface is set at the pulse generator PG, a group of pulses having a predetermined time delay therebetween is generated synchronously with the first signal of the frequency, whereby LB_1 and LB_2 can be controlled by Q-switching. By nulling the pulse separations τ_1, both pulses also can be projected simultaneously.

Figures 22a and 22b show the merging of laser beams, wherein Figure 22a shows a laser beam merging by the beam splitter, in which, by setting the incident angle β_1 and β_2 of the input laser beams LB_1 and LB_2 to a same value within the inherent incident angle of the beam splitter BS, the P wave of LB_1 and S wave of LB_2 can be merged into a coaxial beam LBP, and Figure 22b shows a laser beam merging by the merged mirror TM as shown in embodiment 2. In this case, the input laser beams LB_1 and LB_2 can be merged into parallel but no coaxial beams, and therefore, the diameter of the merged beam LBP is enlarged.

Note that this working by laser beams is not limited to the surface of a roll, but can be applied to any workpiece. The kinds of laser used in this dulling are solid lasers such as YAG, ruby lasers, etc.

The pulse waveforms of the two Q-switched lasers were controlled by the method according to this embodiment to dull the surface of a roll, and the Q-switched laser pulse waveforms were controlled under the following conditions:

Beam splitter:	2 inches in diameter
Laser beam τ_0:	300 nsec
τ_1:	5 μsec
f_0:	20 kHz
Lens focal length FL:	25 mm

Roll shape, length:	1500 mm
diameter:	600 mm
RF, output:	40%
Work time:	about 1 hour

The results were as follows:

The work time was about 1 hour, which obtained the same effect as obtained by using two embodiments of the pulse laser embodiment 2, the inside diameter of the hole formed by dulling was 100 μm and the roughness was 2.2 μm, the transfer to the surface of a steel sheet was as high as 80%, and the abrasion resistance was improved.

According to this embodiment, as above-mentioned, the pulse laser beams can be merged coaxially, so that the focusing system using lens can be made compact and simple and the positioning at the focusing point simplified. Since peak values can be set for individual pulses in the pulse group, it is possible to control the fusing and evaporation of the object in the hole making in the dull-process, thereby permitting holes of an appropriate hardness to be formed. Further, since the separation from one to another pulse group can be controlled, crater formation or drilling further suitable for dulling can be effectively carried out.

Industrial Applicability

According to the invention, it is possible to control the Q-switched pulse waveform of the continuous excitation solid laser to a condition desired for the roll dulling, and to set a convergent beam diameter, a peak value, irradiation time and a irradiated state, etc., of each pulse in the pulse group, and therefore fusing and evaporation of an irradiated article can be controlled, and accordingly, a crater of a proper hardness can be formed and a shape and position of the crater can be controlled, and as a result, it is possible to obtain an arrangement of the crater which is suitable for dulling, and thus provide a remarkably

improved method and apparatus for dulling by a pulse laser, which will have a remarkable affect in industry.

TABLE OF REFERENCE NUMERALS AND SYMBOLS

1: Laser rod
2: Q-switched element
3, 4: Reflecting mirror
5: Radio frequency signal source
6: Diffraction light
7: Resonator
10: Q-switched control system
11: Crater
12: Thermally affected zone
OSC_1 to OSC_4: Laser Cavities
QS_1 to QS_4: Q-switches
Q_1 to Q_4: Q-switched signals
LB_1 to LB_4, LB_{12}, LB_{34}, LBP, LFP: Laser beam
BX_1 to BX_4: Beam expanders
θ_1 to θ_4: Divergence angles
M_1 to M_7, BM_1 to BM_6: Bending mirror
FL: Focusing lens
FP, FP_0, FP_1, FP_2: Focusing point
20: Surface of a roll to be dulled
d_1 to d_4: Focused beam diameters
$f\ell$: Focal length
α: Combination beam angle
f_0: Frequency
PG: Pulse generator
τ_1 to τ_3: Pulse intervals
OM_1 to OM_4: One-shot multivibrators
P_1 to P_4: Laser pulse
W_p: Laser pulse width
TM_1 to TM_3, MM_1 to MM_3: Combination mirrors
BS: Beam splitter

CLAIMS

1. A method for roll-dulling by a pulse laser, in which a continuous wave solid state laser is changed to a pulsed laser by Q-switching, and the roll surface is dulled by said pulsed laser, said method being characterized in that when said pulse laser power is output the cavity loss of a laser oscillator during a pulse off is decreased and a surplus accumulation of excited molecules in the laser resonator is controlled, and as a result, irregularity of the pulse waveform is decreased, and said pulse peak value and the half-power width of the pulse waveform is controlled to full width of half maximum that required for roll-dulling process.

2. A method as claimed in claim 1, characterized in that said cavity loss of the laser oscillator during a pulse off is decreased in accordance with a drop in a power output of a radio-frequency signal applied to a Q-switch.

3. A method as claimed in claim 1 or 2, characterized in that the roll surface is dulled by a laser beam oscillated by a laser oscillator consisting of one of the Q-switch controller, the radio-frequency signal source, and the Q-switch modulator.

4. A method as claimed in claim 1 or 2, characterized in that the roll surface is dulled by a laser beam train formed by laser beams oscillated by the laser oscillators consisting of the Q-switch controller, a plurality of radio-frequency signal sources connected thereto, and the Q switch.

5. A method as claimed in claim 4, characterized in that the plurality of laser beams is made into a laser beam group and the pulse group is formed with a interval of each pulse laser corresponding to a delay, one after another of the Q-switching times of said laser beam group, and controlling respectively the pulse peak

value of the laser to a fixed value, to thereby form a pulse group suitable for dulling the roll surface.

6. A method as claimed in claim 5, characterized in that a each beam diameter of the plurality of laser beams is enlarged by the beam expander and said laser beams are combined into a laser beam group made parallel or nonparallel.

7. A method as claimed in claim 4 or 5, characterized in that the component of each laser of at least two laser beams in the plurality of laser beams is separated and then combined coaxially, and then the roll surface is irradiated by said combined laser beams.

8. An apparatus for roll-dulling by a pulsed laser, in which the Q-switch controller comprises a pulse oscillator for determining a pulse repetition rate and the output power of a radio-frequency signal and a one-shot multi vibrator for determining the pulse interval, and the laser oscillator comprises a radio-frequency signal source to which a power output exchange signal is applied by the Q-switch controller and the Q-switching is effected upon output of the signal to said radio-frequency source.

9. An apparatus as claimed in claim 8, characterized in that, in accordance with the laser oscillator which comprises the Q-switch controller, the plural radio-frequency signal source connected thereto and the Q-switch, a pulse interval is provided between each pulse and the pulse peak value of each pulse is controlled, and the pulse laser group consists of the above plurality of pulses.

10. An apparatus as claimed in claim 9, characterized in that a laser beam expander is provided between the laser oscillator and the mirror and the laser beams are focused on the laser beam grouping parallel or nonparallel state.

11. An apparatus as claimed in claim 8 or 9, characterized in that the beam splitter which

receives a laser beams from a pair of at least two laser oscillators separates each laser component and combines them coaxially.

Fig. 1a

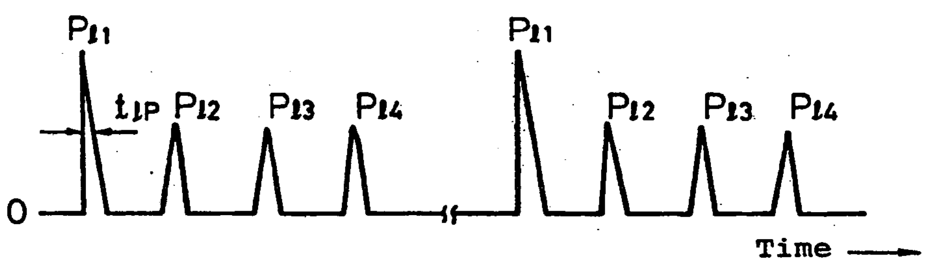

$P_{\ell 1}$
$t_{\ell P}$
$P_{\ell 2}$
$P_{\ell 3}$
$P_{\ell 4}$
$P_{\ell 1}$
$P_{\ell 2}$
$P_{\ell 3}$
$P_{\ell 4}$
0
Time

Fig. 1b

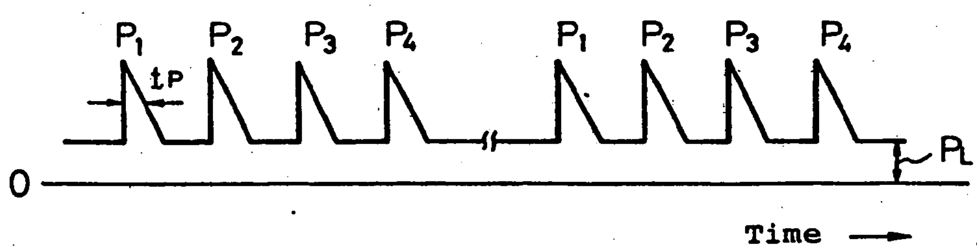

P_1
t_P
P_2
P_3
P_4
P_1
P_2
P_3
P_4
P_L
0
Time

Fig. 2

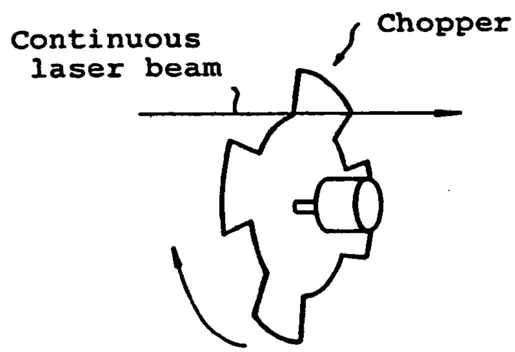

Chopper
Continuous laser beam

Fig. 3

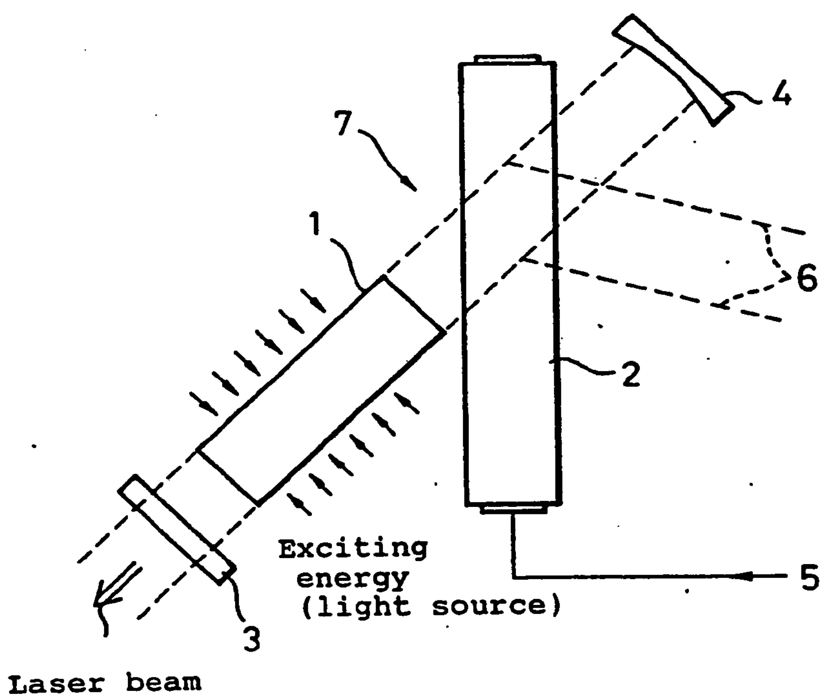

4
7
1
6
2
Exciting energy (light source)
5
3
Laser beam

Fig. 4a

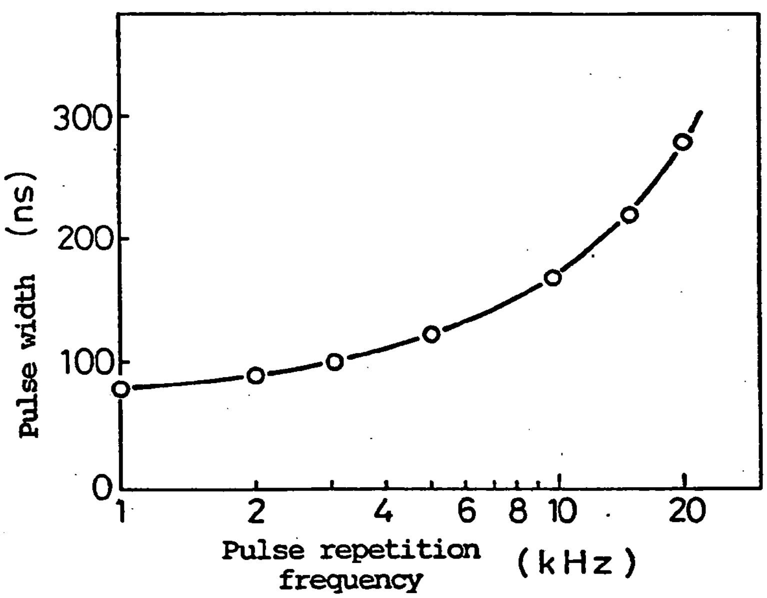

300
200
100
0
(ns)
Pulse width
1
2
4
6
8
10
20
Pulse repetition frequency
(kHz)

Fig. 4b

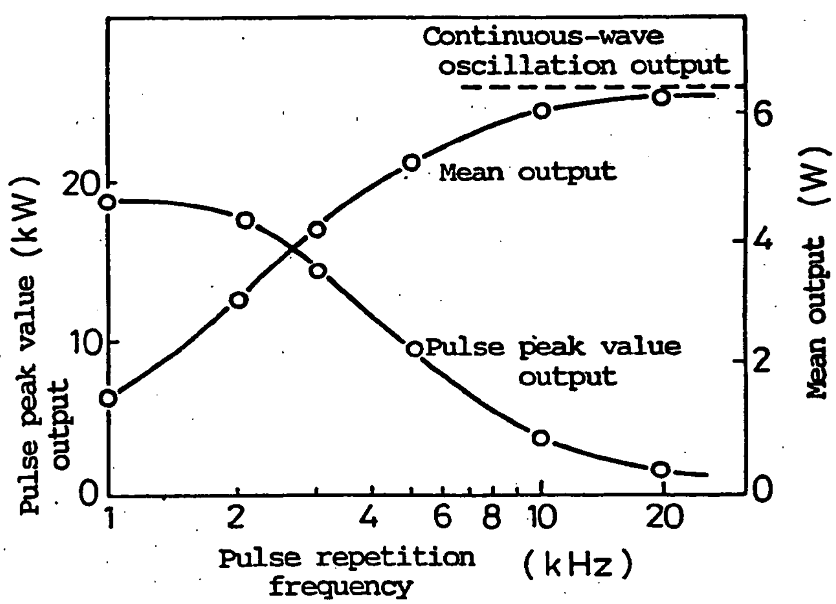

Continuous-wave oscillation output
Mean output
Pulse peak value output
20
10
0
Pulse peak value output (kW)
6
4
2
0
Mean output (W)
1
2
4
6
8
10
20
Pulse repetition frequency
(kHz)

Fig. 5

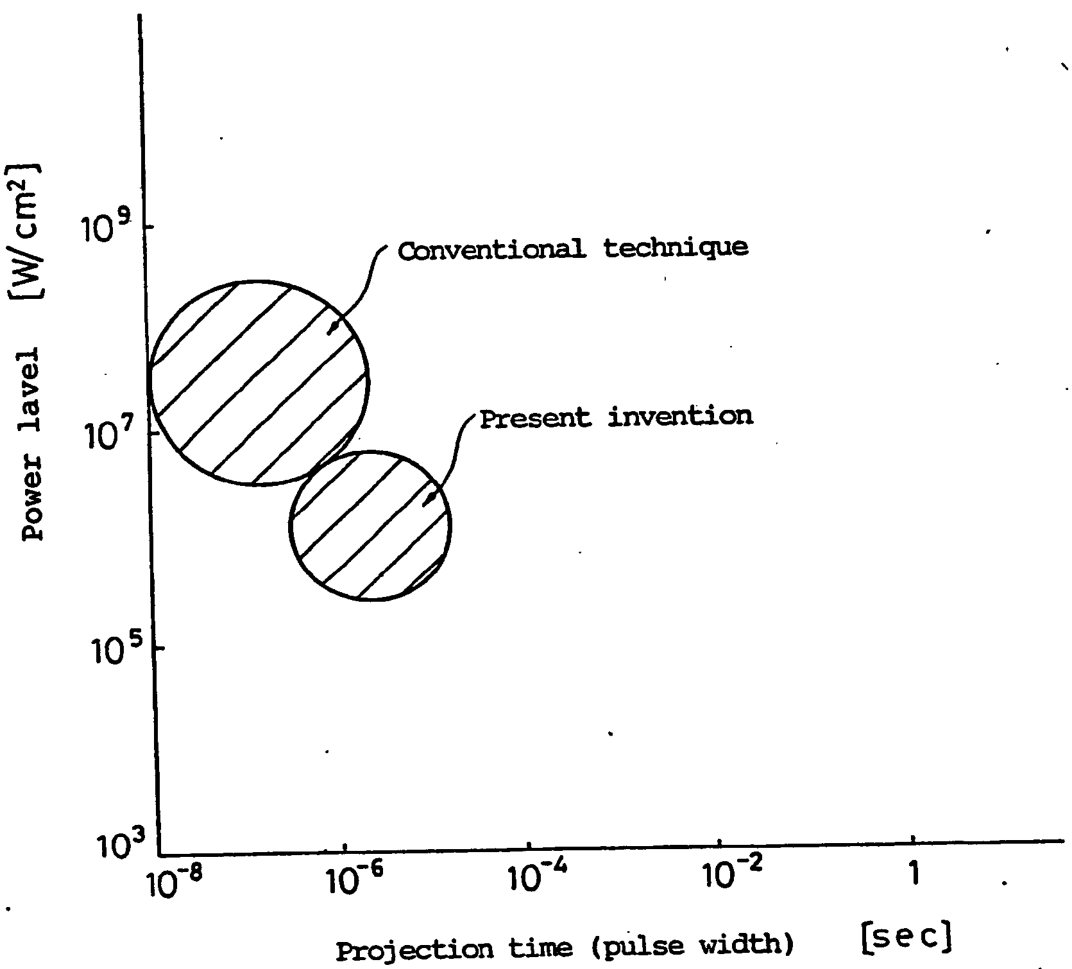

Power lavel [W/cm²]
10⁹
10⁷
10⁵
10³
Conventional technique
Present invention
10⁻⁸
10⁻⁶
10⁻⁴
10⁻²
1
Projection time (pulse width) [sec]

Fig. 6

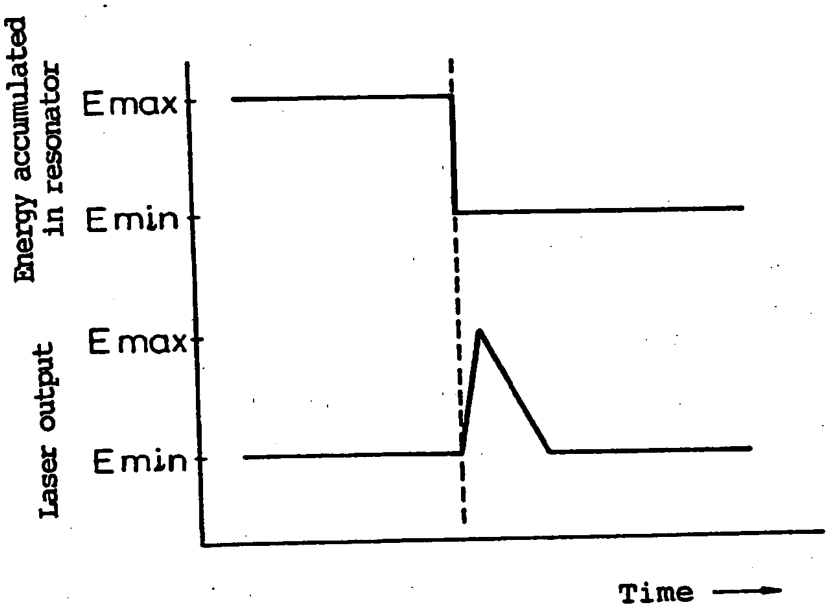

Energy accumulated in resonator
Emax
Emin
Laser output
Emax
Emin
Time

Fig. 7a

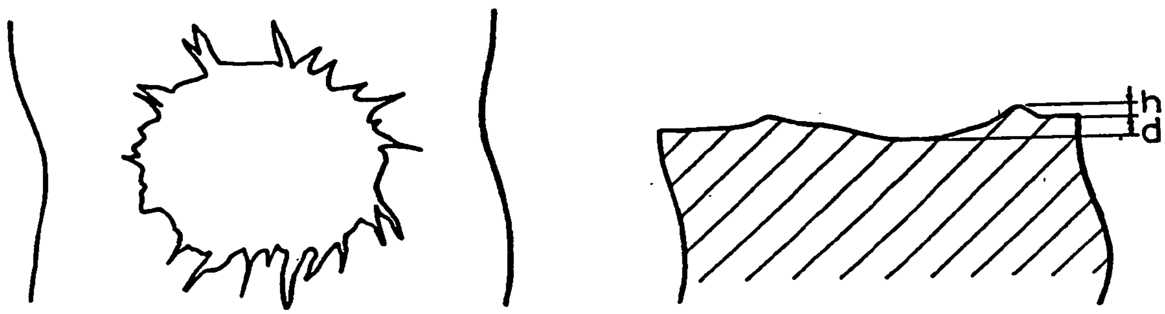


Fig. 7b

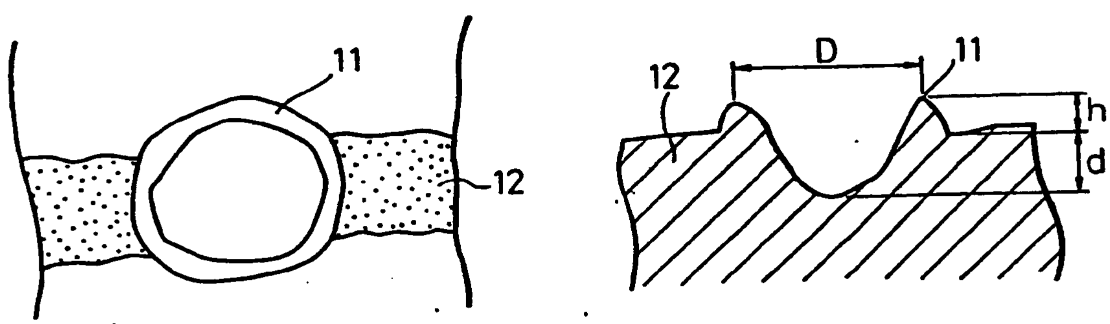


Fig. 8

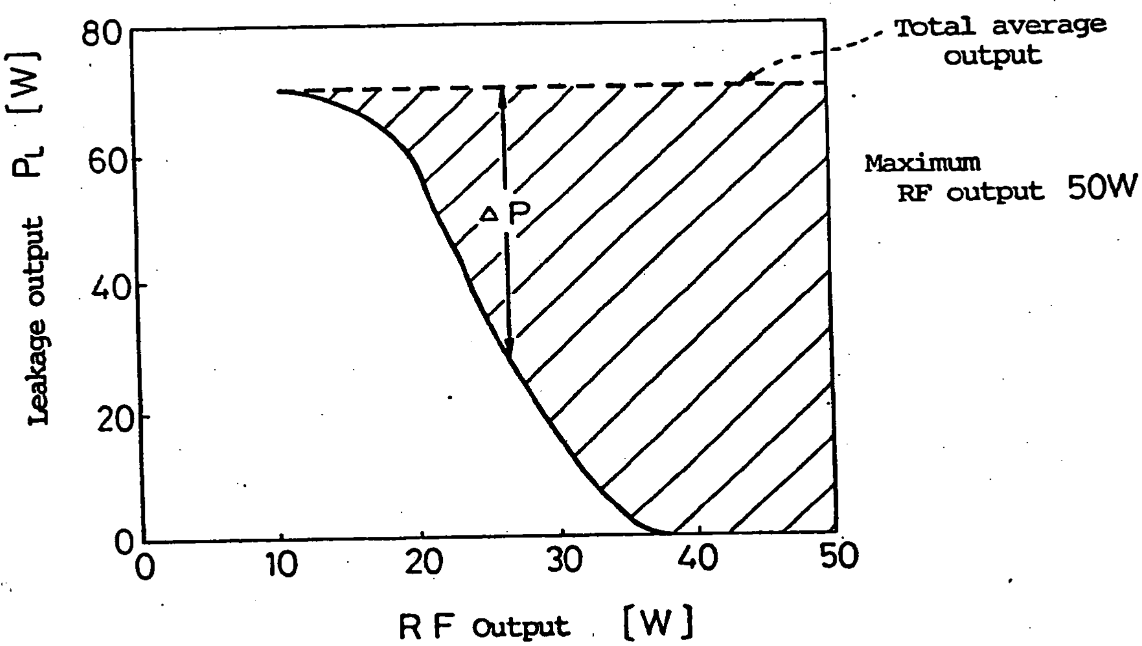

80
60
40
20
0
Leakage output P_L [W]
0
10
20
30
40
50
RF output [W]
ΔP
Total average output
Maximum RF output 50W

Fig. 9

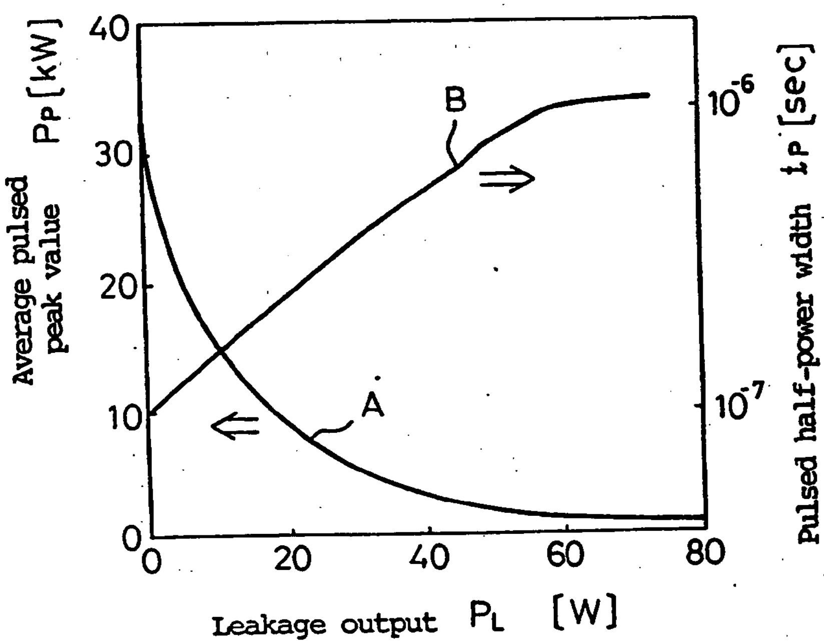

40
30
20
10
0
Average pulsed peak value P_P [kW]
B
A
10^{-6}
10^{-7}
Pulsed half-power width t_P [sec]
0
20
40
60
80
Leakage output P_L [W]

Fig. 10

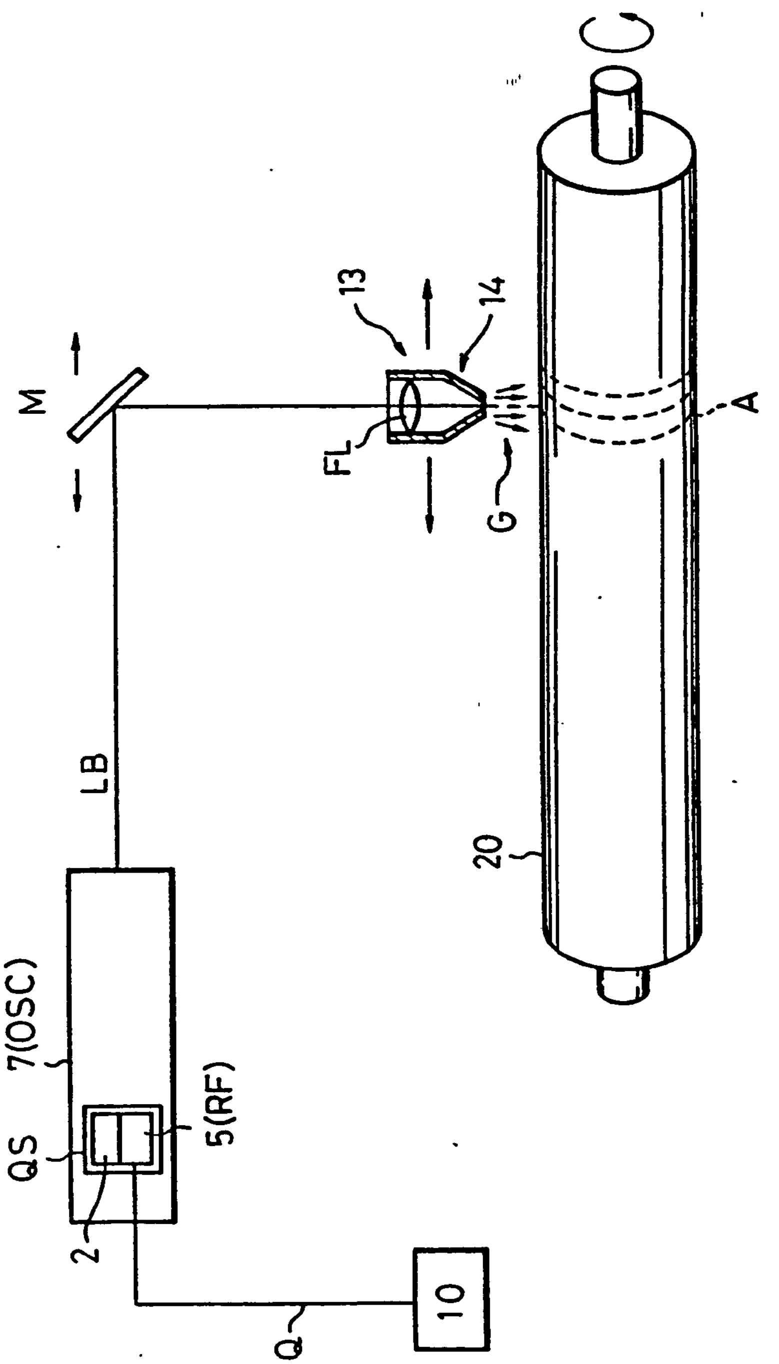


Fig.11

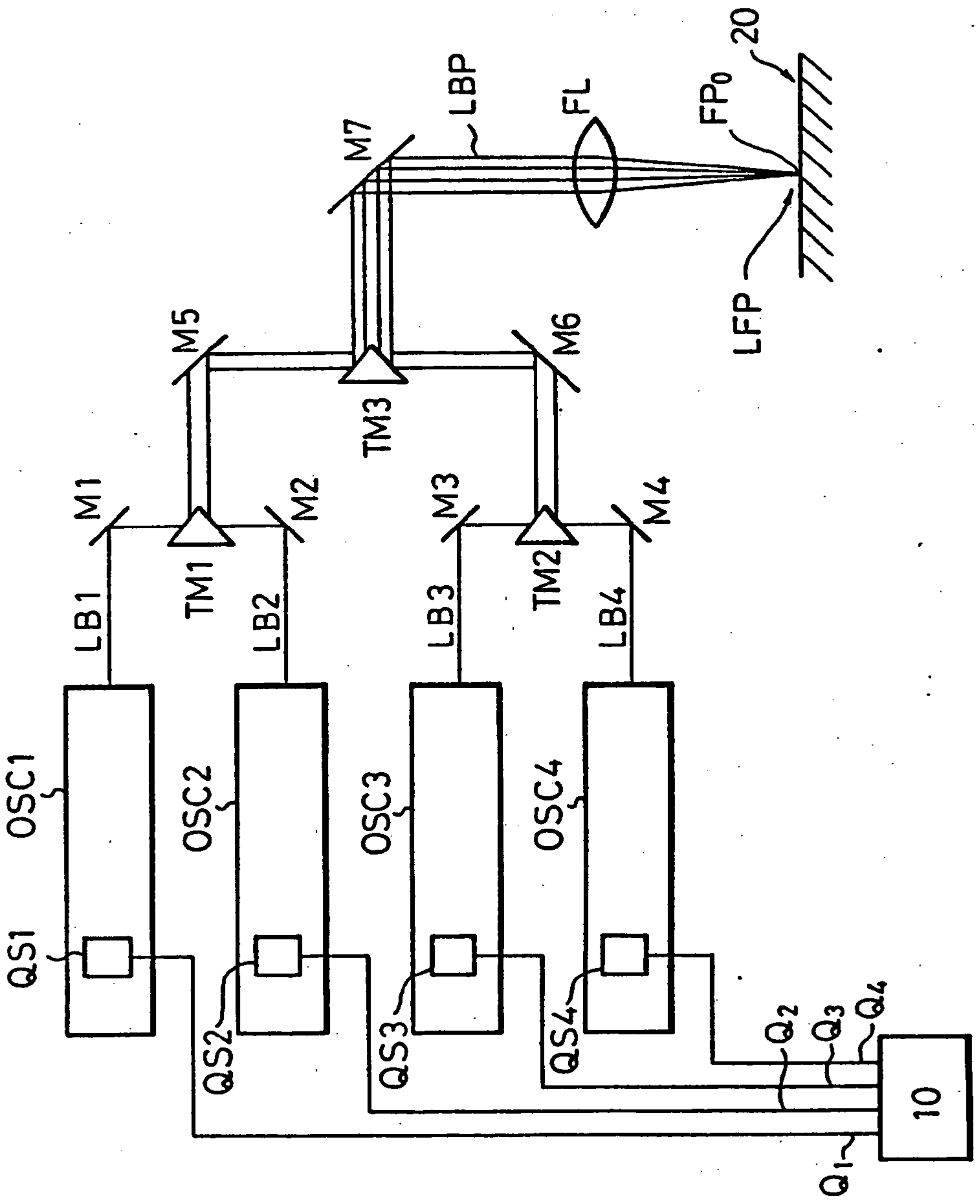
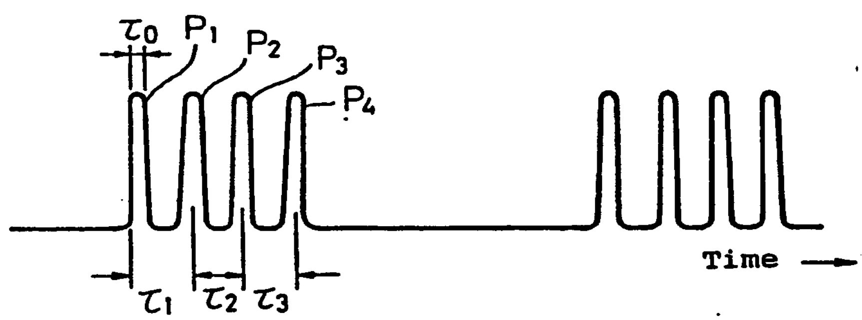
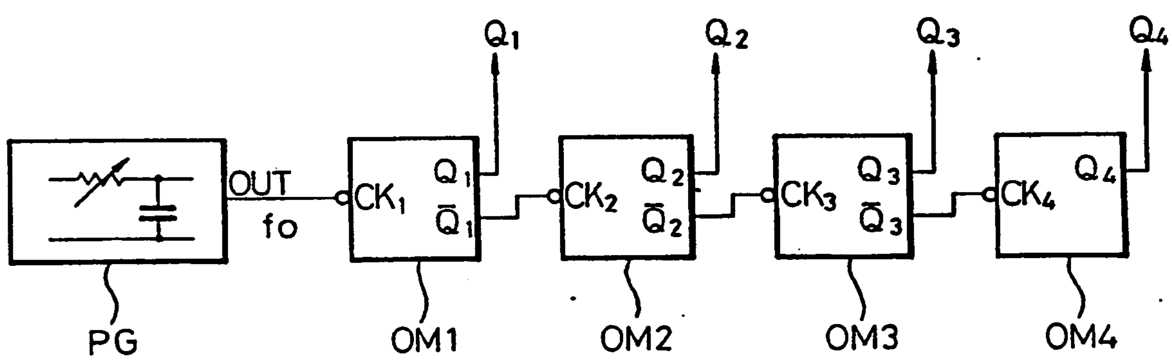

OSC1
OSC2
OSC3
OSC4
QS1
QS2
QS3
QS4
LB1
LB2
LB3
LB4
M1
M2
M3
M4
M5
M6
M7
TM1
TM2
TM3
LBP
FL
FP0
LFP
20
Q1
Q2
Q3
Q4
10

Fig. 12



τ0
P1
P2
P3
P4
τ1
τ2
τ3
Time

Fig. 13



Q1
Q2
Q3
Q4
OUT
fo
CK1
Q1
Q̄1
CK2
Q2
Q̄2
CK3
Q3
Q̄3
CK4
Q4
PG
OM1
OM2
OM3
OM4

Fig. 14

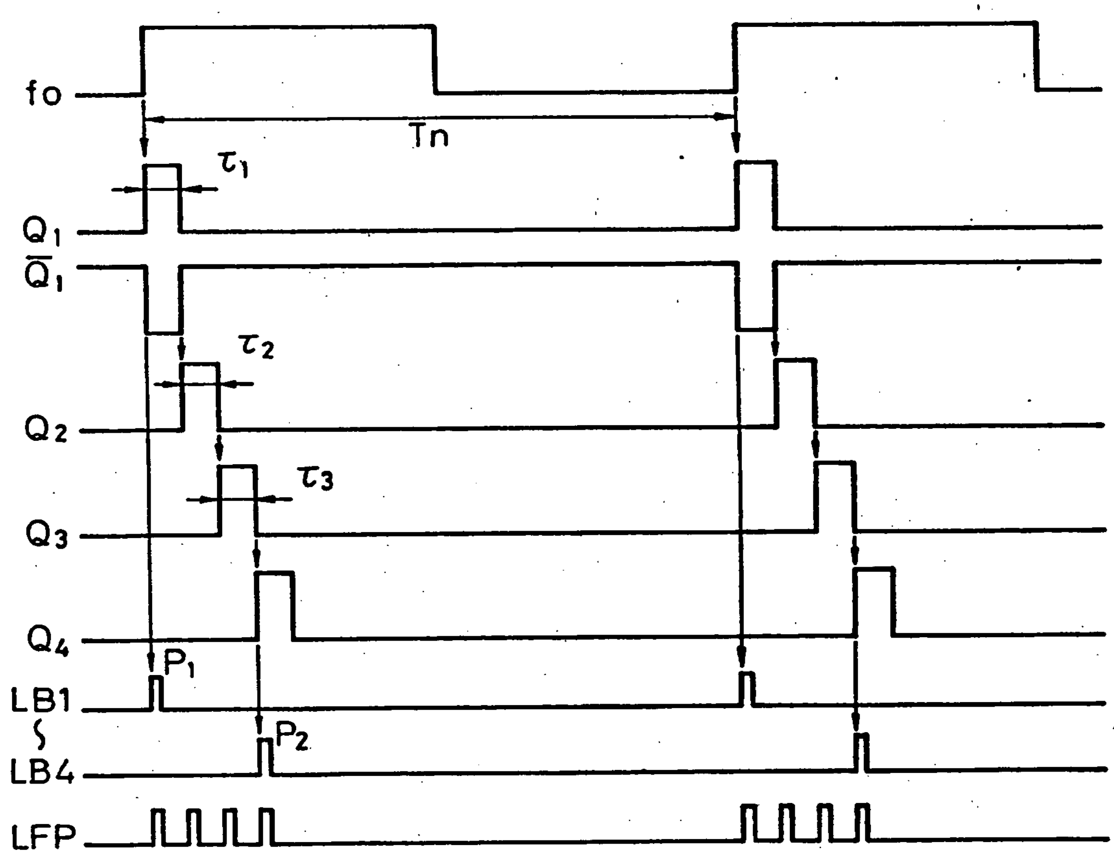


Fig.15

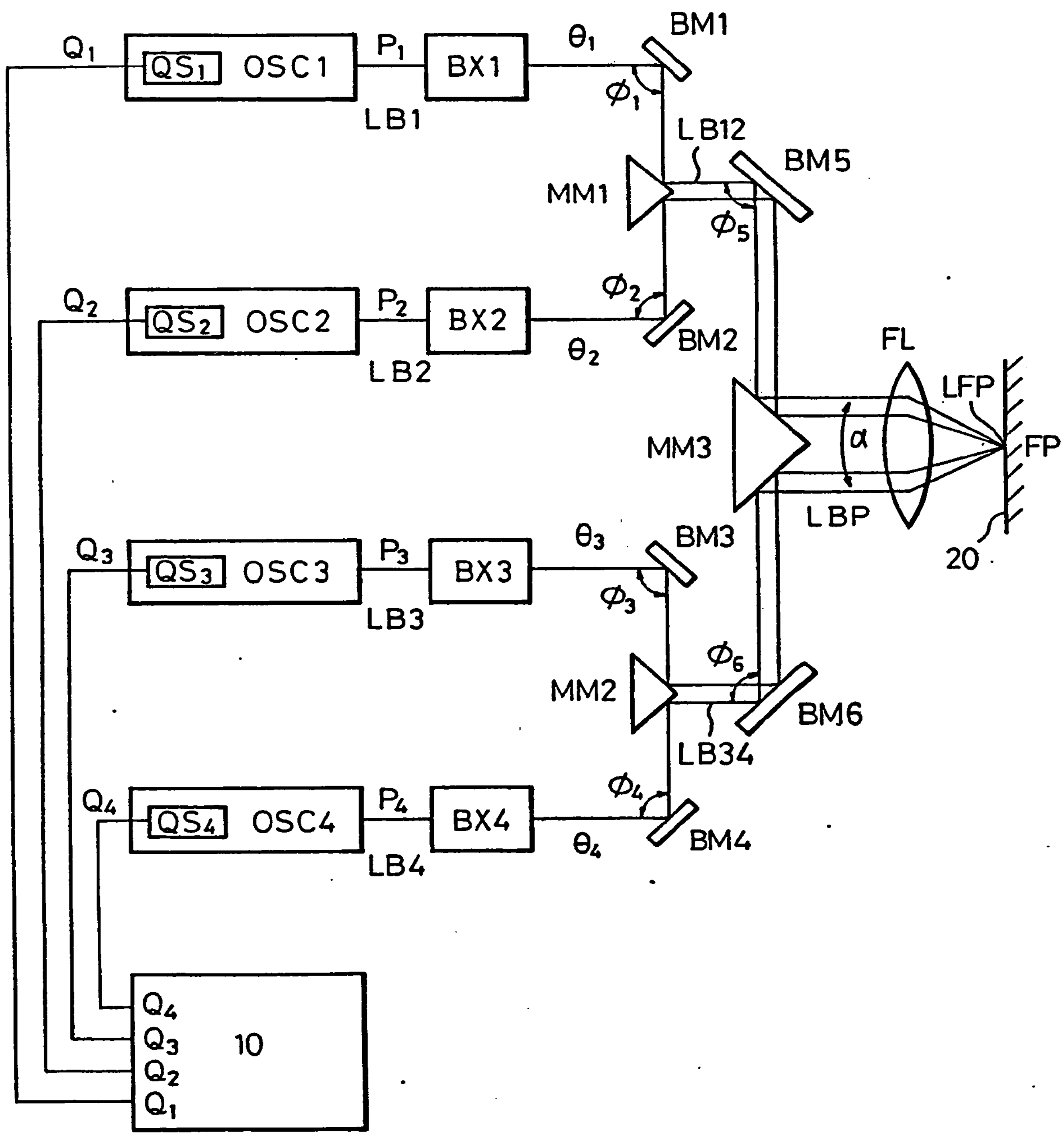

Q1
QS1
OSC1
P1
BX1
θ1
BM1
φ1
LB1
LB12
BM5
MM1
φ5
Q2
QS2
OSC2
P2
BX2
φ2
BM2
θ2
LB2
FL
LFP
MM3
α
FP
LBP
20
Q3
QS3
OSC3
P3
BX3
θ3
BM3
φ3
LB3
φ6
MM2
BM6
LB34
Q4
QS4
OSC4
P4
BX4
φ4
BM4
θ4
LB4
Q4
Q3
10
Q2
Q1

Fig.16

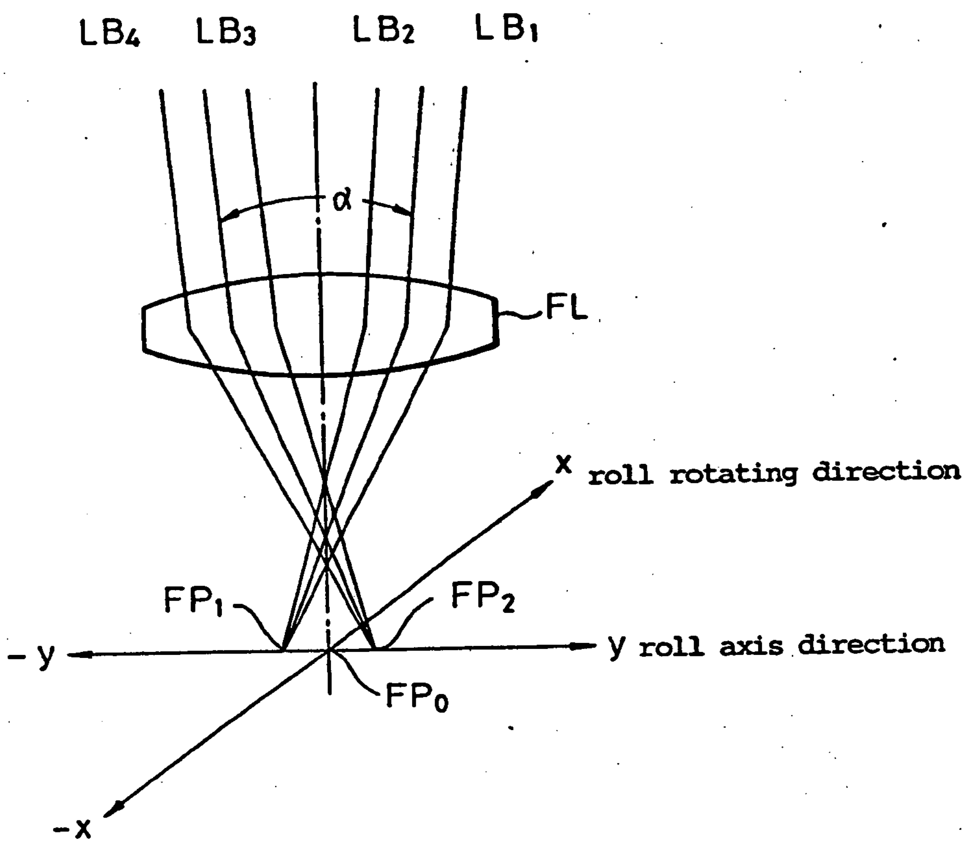

LB4
LB3
LB2
LB1
α
FL
x roll rotating direction
FP1
FP2
-y
y roll axis direction
FP0
-x

Fig. 17

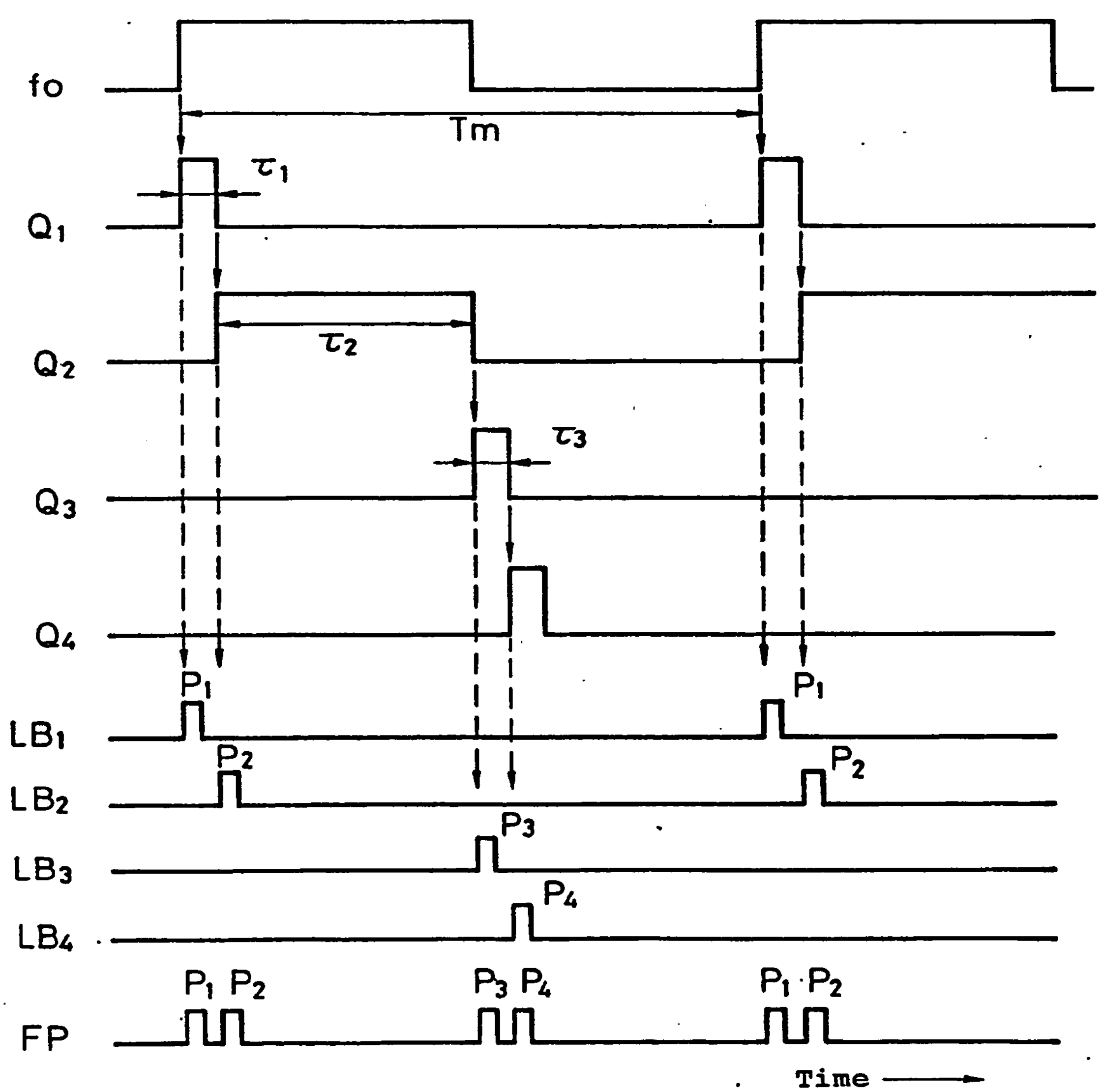

fo
Tm
Q1
τ1
Q2
τ2
Q3
τ3
Q4
P1
LB1
P2
LB2
P3
LB3
P4
LB4
P1 P2
P3 P4
P1 P2
FP
Time

Fig. 18a

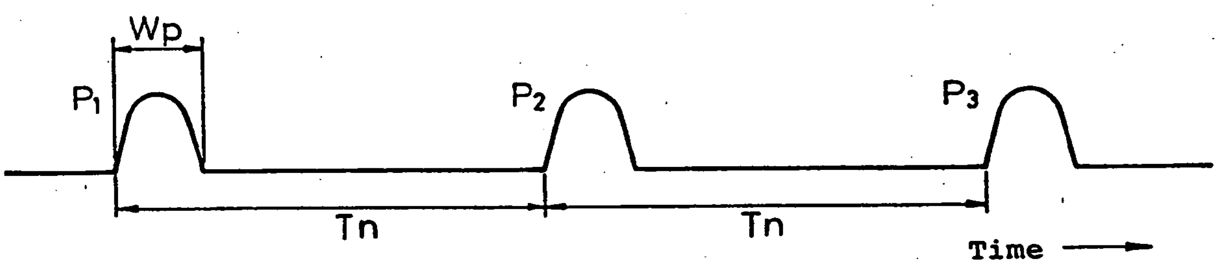


Fig. 18b

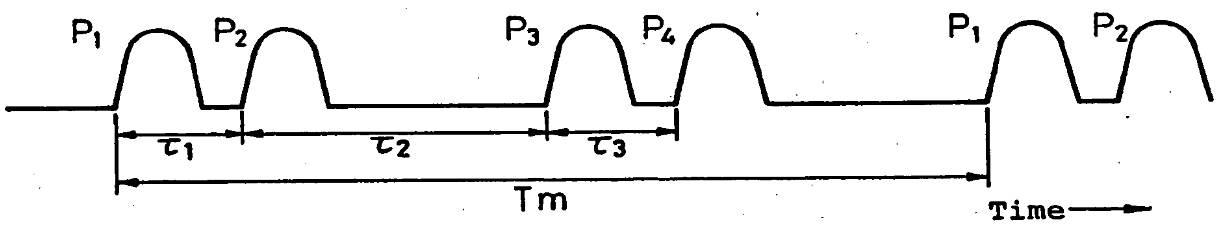


Fig. 18c

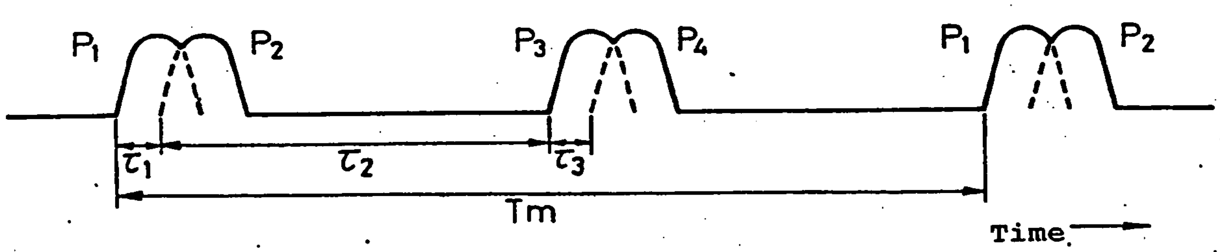


Fig.19

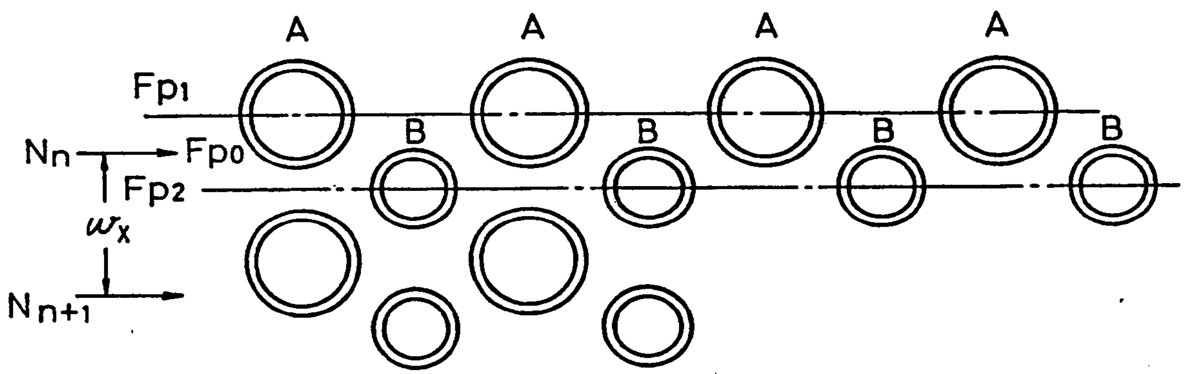


Fig.20

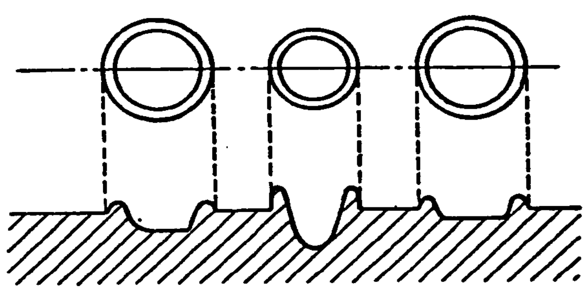


Fig. 21a

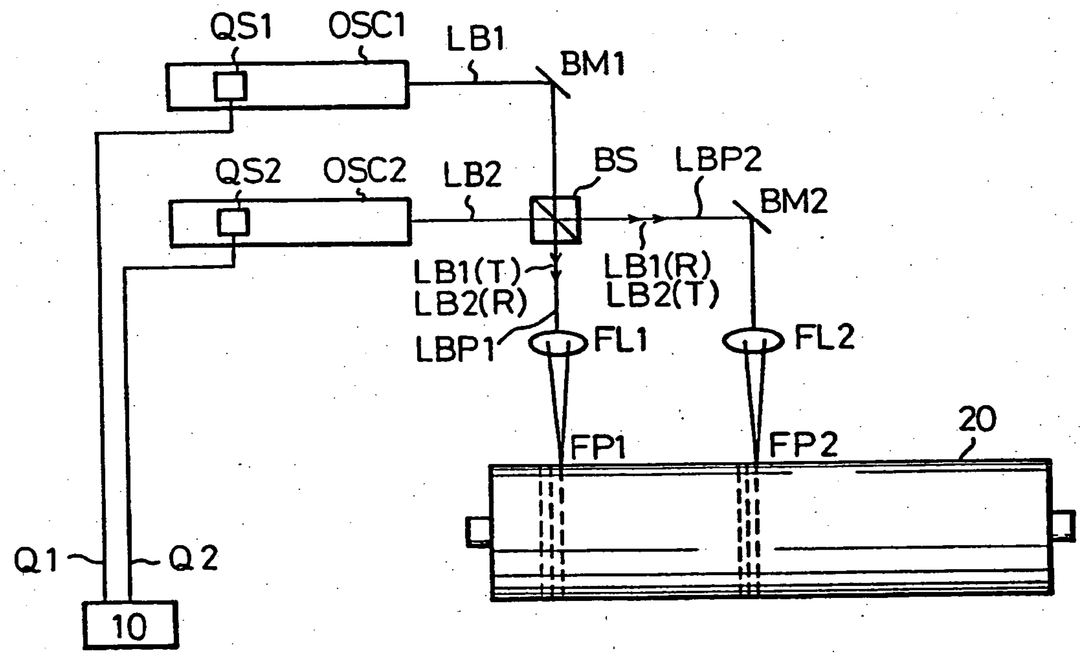


Fig. 21b

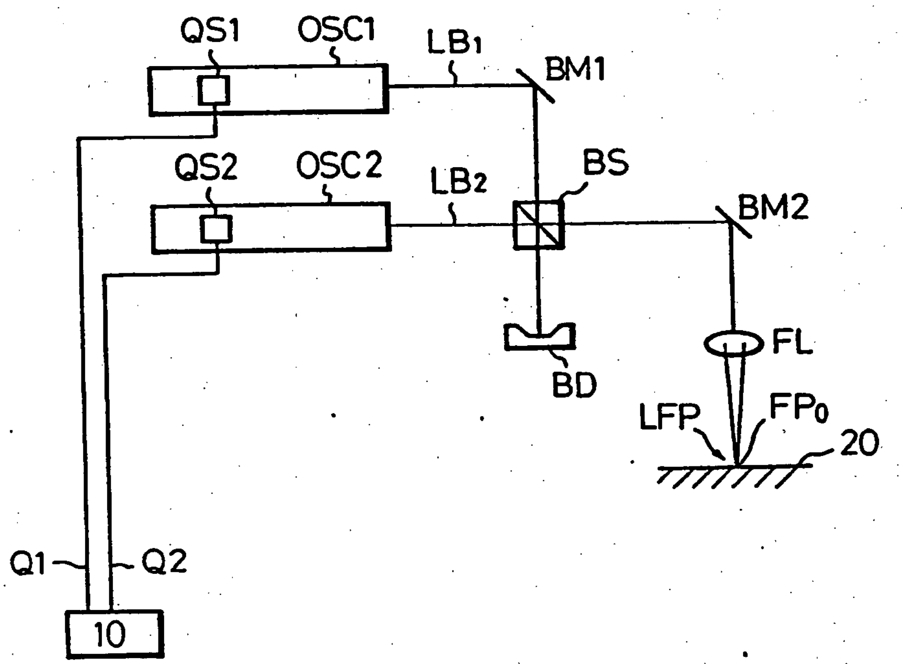


Fig. 22a

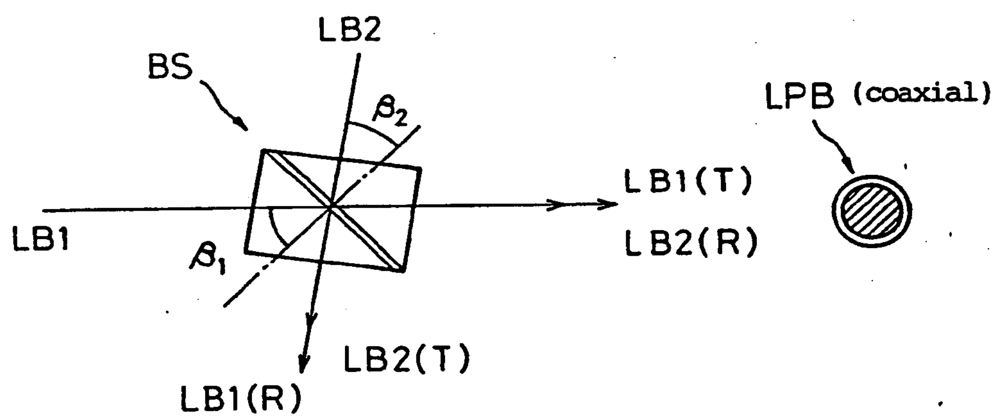
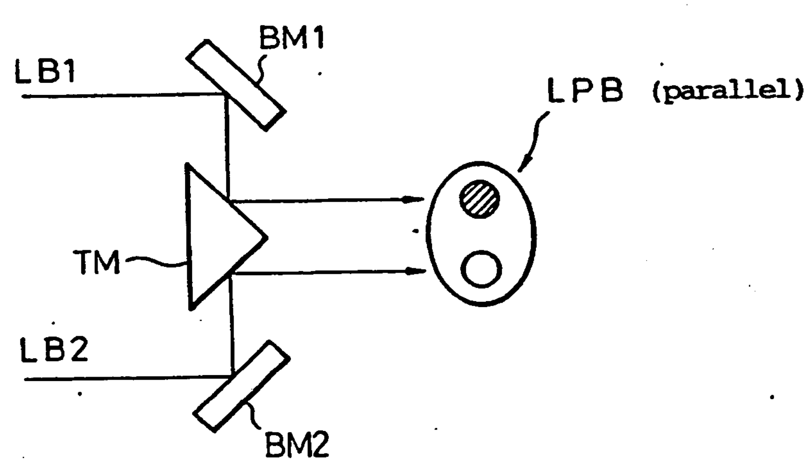


Fig. 22b



INTERNATIONAL SEARCH REPORT

International Application No PCT/

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl^4 B23K26/00, H01S3/11

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC	B23K26/00-26/18, H01S3/11

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

Jitsuyo Shinan Koho	1926 - 1987
Kokai Jitsuyo Shinan Koho	1971 - 1987

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	JP, A, 58-79788 (NEC Corporation) 13 May 1983 (13. 05. 83) (Family: none)	1-11

* Special categories of cited documents: [10]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
May 10, 1988 (10. 05. 88)	May 23, 1988 (23. 05. 88)
International Searching Authority	**Signature of Authorized Officer**
Japanese Patent Office	

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